

## LINK MECHANISM TO DETERME THE POSITION AND DIRECTION

## BACKGROUND OF THE INVENTION

## a) Field of the Invention

The present invention is a link mechanism to determine a position and direction in three dimensional space. Such a link mechanism is applicable to determine the position and direction of a surgical assist apparatus, an end effector of a robot (manipulator) or the like.

## b) Description of the Related Art

In MR/T (magnetic resonance and therapy), fusion of diagnosis and treatment, it is necessary that the presence and function of a medial equipment do not generate artifacts (such as noises and ghost) on the image. The mutual influence between a medical equipment and MRI is called MR compatibility.

Surgical assist robots are promising to be used in MR/T.

However, since robot mechanism generally uses many metal components such as steel components, electromagnetic motors, electric sensors and the like, it has been difficult to realize MR compatibility. In particular, the end effector, which is used near at a patient, are required to have a very small magnetic susceptibility and low electrical noise radiation. It is therefore difficult to use a complicated mechanism, active mechanical elements such as motors, and various types of sensors.

Under such restrictions, surgical assist robot for MR/T must realize a mechanism to determine at least the position (x y z) and angles  $\theta$  and  $\phi$  to define the direction in 3 dimensional space. It is also desired that the end effector is cleanable and sterilizable. The end effector is also required to be simple and compact so as not to intercept the view field and

the work area of the surgeon. In addition, the output power of actuator should be as small as possible to maintain safety.

There are many conventional mechanisms to define the position ( $x y z$ ) and angles  $\theta$  and  $\phi$ . A typical example of such mechanisms is arm type robot. The arm type robot uses a number of arm links interconnected by joints.

The arm type robot usually has actuators at the joints otherwise it employs wire mechanism, shaft, and so on to transmit the driving power. The actuator is difficult to maintain MR compatibility, and cannot maintain cleaning and sterilization unless a water-proof process is performed strictly. Since the transmission mechanism is composed from many parts and mechanically complicated, the power loss can be significant.

requires a number of power transmission components so that it is mechanically complicated and a power loss cannot be neglected.

A parallel link mechanism, typically a hexa pod type robot, can be designed to place actuators remotely from the end effector. However, since links concentrate near at the end effector, the mechanical structure is complicated.

By designing the end effector being long, it may be MR compatible, cleanable and sterilizable.

In this case, however, its precision is degraded and stronger actuators are required. Such end effector can be complicated and bulky, and consequently intercept the view field of the surgeons.

Under such circumstances, the link mechanism to determine the position and angles have long been desired, which mechanism has a high precision of position and angle determination, does not require strong

actuators, and is mechanically simple and easy to MR compatibility, cleaning and sterilization.

## SUMMARY OF THE INVENTION

The invention has been made under such circumstances. The object of the present invention is to realize a link mechanism for determining the position and angles, which mechanism has a high precision of position and angle determination, does not require strong actuators, and is mechanically simple and easy to MR compatibility, cleaning and sterilization, and in which an end effector does not intercept the field of view of the surgeon.

To achieve the above object, the invented link mechanism has the following features: an axial rod; and two spherical bearings to support the axial rod, the two spherical bearings being capable of changing positions, wherein the motion of one of the two spherical bearings relative to the axial rod along the axis is constrained, and the another spherical bearings can travel along the axial rod R.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of an implementation of an end effector of a robot, a link mechanism based on this invention.

Figure 2 is a front view of the link mechanism of the embodiment.

Figure. 3 is a diagram illustrating the motion of spherical bearings.

Figure. 4 is a diagram showing a relation among the positions and directions of spherical bearings  $P_1$  and  $P_2$  and an axial rod R.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the invention will be described with reference to the accompanying drawings.

In Fig. 1, reference numeral 11 generally represents a end effector. A link mechanism of the invention is assembled in this robot end effector 11. The end effector 11 has a pair of elongated arms 12 and 13. This pair of arms 12 and 13 cooperatively maneuver to work a subject. The base portion 14 of the arm 12 is fixed to the outer wheel 3 or the inner wheel 2 of the spherical bearing  $P_1$  of the link mechanism 1 of this invention to be described later, whereas the base portion 15 of the other arm 13 is fixed to the outer wheel 3 or the inner wheel 2 of the spherical bearing  $P_2$ .

As shown in Figures. 1, 2 and 3, the link mechanism 1 of this invention is composed of two spherical bearings  $P_1$  and  $P_2$  and an axial rod R which is a rigid element interconnecting the spherical bearings  $P_1$  and  $P_2$ .

The spherical bearing  $P_1$  travels in three dimensional space (or in a partial space thereof), whereas the position of the spherical bearing  $P_2$  is constrained in three dimensional space or two-dimensional plane (or in a partial space or plane thereof) relative to the spherical bearing  $P_1$ .

Each of the spherical bearings  $P_1$  and  $P_2$  is composed of the inner wheel 2 and the outer wheel 3. The inner and outer wheels 2 and 3 share the common centroid so that they relatively rotate around this point.

It is common specification of widely available spherical bearings. The axial rod R is fixed to the inner wheel 2 or outer wheel 3 of the spherical bearing  $P_1$  which wheel is not fixed to the arm 12. The axial rod R is

fixed neither to the inner wheel 2 nor to the outer wheel 3 of the spherical bearing  $P_2$ . The spherical bearing  $P_2$  can therefore slide along the axial rod R as  $P_2$  moves.

This link mechanism 1 can be made of only passive mechanical elements. Although sensors are not essential to determine the position and angles, such sensors may be used.

The spherical bearings  $P_1$  and  $P_2$  are driven by drivers (not shown). Such drivers and a method of determining the positions of the spherical bearings  $P_1$  and  $P_2$  may be any desired drivers and method.

The determination of the position and direction of the axial rod R of the link mechanism 1 constructed as above is as the following.

The representative three-dimensional coordinate (x y z) of the whole link mechanism 1 is defined by the position of the spherical bearing  $P_1$ , and at the same time, the direction (angles  $\theta$  and  $\phi$ ) of the axial rod R is determined from a motion of the spherical bearing  $P_2$  relative to the spherical bearing  $P_1$ .

As the spherical bearing  $P_2$  is driven, it has a relative displacement along of the axial rod R. To allow this displacement, it is necessary that the spherical bearing  $P_2$  can slide along the axial rod R.

Figure 4 is a diagram showing relation of the spherical bearings  $P_1$ ,  $P_2$  and the axial rod R in terms of their position and direction.

The angles  $\phi$  and  $\theta$  of the polar coordinate system satisfy the following equations:

$$x' = r \cos \phi \sin \theta$$

$$y' = r \sin \phi \sin \theta$$

$$z' = r \cos \theta$$

where

$$x' = x_2 - x_1$$

$$y' = y_2 - y_1$$

$$z' = z_2 - z_1$$

$$r^2 = x'^2 + y'^2 + z'^2$$

The length of the axial rod R should be longer than the maximum length of r.

In practice, the width of the spherical bearings  $P_1$  and  $P_2$  along the axial direction is additionally required. If r becomes longer than the length of the axial rod R, the spherical bearing  $P_2$  is dismounted from the axial rod R.

The link mechanism of this invention can be composed from substantially only two spherical bearings and one axial rod. These components can be made of paramagnetic material having small magnetic susceptibility, such as ceramics, glass fiber reinforced material, carbon fiber reinforced material, wood, and non-ferrous metal. Active mechanical elements and sensors are not essential. This link mechanism can be excellent in MR compatibility, detachable, cleanable and sterilizable.